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AN/TAC-1 TELEPHONE BATTERY SUPPLY

By

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This report describes the design, operation, and testing of the telephone battery subassembly of the AN/TAC-1. The subassembly doubles the unregulated 28 V dc prime power source of the AN/TAC-1 and provides 56 V dc to operate up to two external digital subscriber voice terminals operating in the common battery mode.

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18. Power Supply
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SECTION 1

INTRODUCTION

This paper describes the Telephone Battery Supply Subassembly of the AN/TAC-1. The AN/TAC-1 is a 65-pound, throw-in-the-mud box designed to transmit multichannel telephone traffic over lightweight fiber optic cable up to 6 kilometers in length. The unit is ruggedized for use in mobile ground environments. The primary use for the AN/TAC-1 will be to remote radiating radio frequency transmitters, such as the AN/TRC-170 Troposcatter Radio, from personnel using them. This protects the users from radiation-seeking missiles fired at the transmitting equipment by hostile aircraft.

1.1 REQUIREMENT

The Telephone Battery Supply Subassembly of the AN/TAC-1 provides power for a maximum of two digital subscriber voice terminals (DSVTs), TSEC/KY-68 (E-2), operating in the common battery mode, or two digital non-secure voice terminals (DNVTs), TA-954-TT. During operation, current flows over one pair of the four-wire loop interface and returns over the other pair. The specified input voltage across the terminal pairs of the DSVT is 24 to 56 V dc, and the specified power consumption in the standby and operating states is 0.6 and 1.65 watts maximum, respectively. Therefore, if the load is purely resistive in nature, the loop currents will range from approximately 11 to 69 milliamps.

1.2 SOLUTION

The highest voltage available inside the AN/TAC-1 is 28 V dc, half of that required to power a DSVT at the end of a long loop. Thus, a circuit to double the 28 V dc prime voltage is required. The conventional voltage-doubler circuit immediately comes to mind; however, this circuit requires an alternating current source rather than the direct current source of the AN/TAC-1. Since dc can be chopped by a transistor switch to provide pseudo-ac, the two ideas have been combined, and the result is the "active voltage doubler." This circuit has been prototyped and tested. It proves to be simple, reliable, and volumetrically efficient. Therefore, it has been chosen to provide common battery power for the DSVT.

1.3 FAULT PROTECTION

In a tactical environment, the remote telephone loops are in constant jeopardy of being run over by a tank, truck, or personnel carrier. This could cause the conductors of the field wire to short-circuit. A short-circuit condition could overload the AN/TAC-1 28 V dc supply and result in failure of the entire system. Therefore, short-circuit protection is required. Additionally, rather than employing simple current limiting protection, which would increase internal power dissipation for the duration of the short, it was decided to completely disconnect the shorted loop. This decision led to another problem: how would the shorted loop be restored to service? It was decided that the loop should be automatically restored to service when the short was removed. These requirements were satisfied by what became known as the "putt-putt" circuit. It received this nickname because it causes the indicator loop on the power control panel to flash approximately once every 2 seconds. When the loop is shorted, it "putts." When the loop is operational, it is on continuously.

The putt-putt circuit senses the output voltage on the remote telephone loop. When it is greater than 20 V dc, the indicator lights to show a normal condition. Should a short-circuit occur, a transistor switch in series with the loop is cut off to remove power, and the indicator lamp is simultaneously turned off. After a couple of seconds, a free-running timer forces the series transistor switch on for a fraction of a second. If the overload has been corrected, the output voltage will rise above 20 V dc and the series switch will be latched on. If the overload has not been corrected, the voltage will remain below 20 V dc. When the timer expires, the series switch will be reopened. The indicator light flashes briefly during the sense periods, but remains off for most of the time an overload condition exists. During sensing periods, another transistor limits the series switch current to approximately 250 milliamps, maximum. Therefore, the load resistance must be greater than approximately 96 ohms before power is fully restored to the loop.

SECTION 2

FUNCTIONAL DESCRIPTION

2.1 BLOCK DIAGRAM

A block diagram of the telephone battery supply is shown in figure 1. It consists of two circuits: (1) active voltage doubler and (2) short-circuit protection. The short-circuit protection circuit is used twice on the printed wiring assembly, once to protect remote telephone loop 1 (TEL1) and once to protect remote telephone loop 2 (TEL2).

2.2 ACTIVE VOLTAGE DOUBLER

The function of the active voltage doubler is to double the nominal +28 V dc internal prime voltage source of the AN/TAC-1, and provide nominal +56 V dc to operate two telephone loops. To accomplish this function, the active voltage doubler employs two power switches, two high-speed diodes, two high-frequency capacitors, and an integrated circuit controller. These components charge one capacitor to +28 V. This capacitor is then switched series-aiding with the +28 V dc supply to charge a second capacitor to +56 V dc. The second capacitor acts as a reservoir from which energy may be drawn to power the remote telephone loops.

2.2.1 First Switching Cycle

Figure 2 is a simplified functional diagram of circuit operation during the first of two switching cycles. Power switch U5 has been closed and U4 has been opened by controller U3. Capacitor C14 changes to +28 V, with the polarity shown, through CR4 and U5. Since the voltage on the positive terminal of capacitor C15 is greater than +28 V, diode CR5 is reversed biased and is effectively an open circuit. Therefore, no current flows from the +28 V dc supply into C15 during this cycle.

2.2.2 Second Switching Cycle

Figure 3 is a simplified functional diagram of circuit operation during the second of two switching cycles. Controller U3 has opened power switch U5 and closed power switch U4. This action places the +28 V dc supply voltage in series with the 28 V across capacitor C14.

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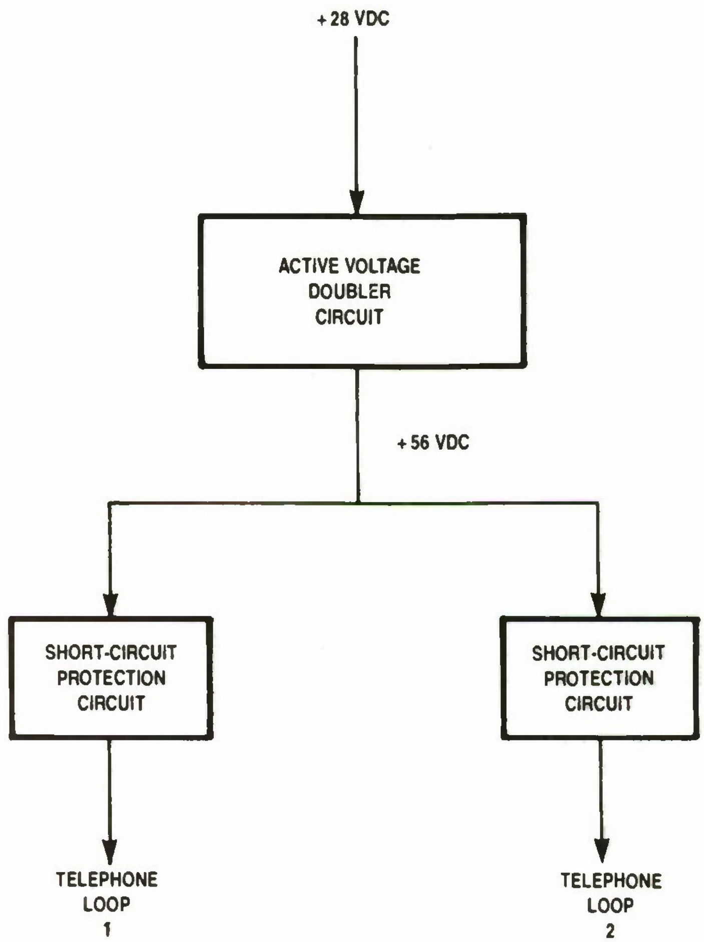

Figure 1. Telephone Battery Supply Block Diagram

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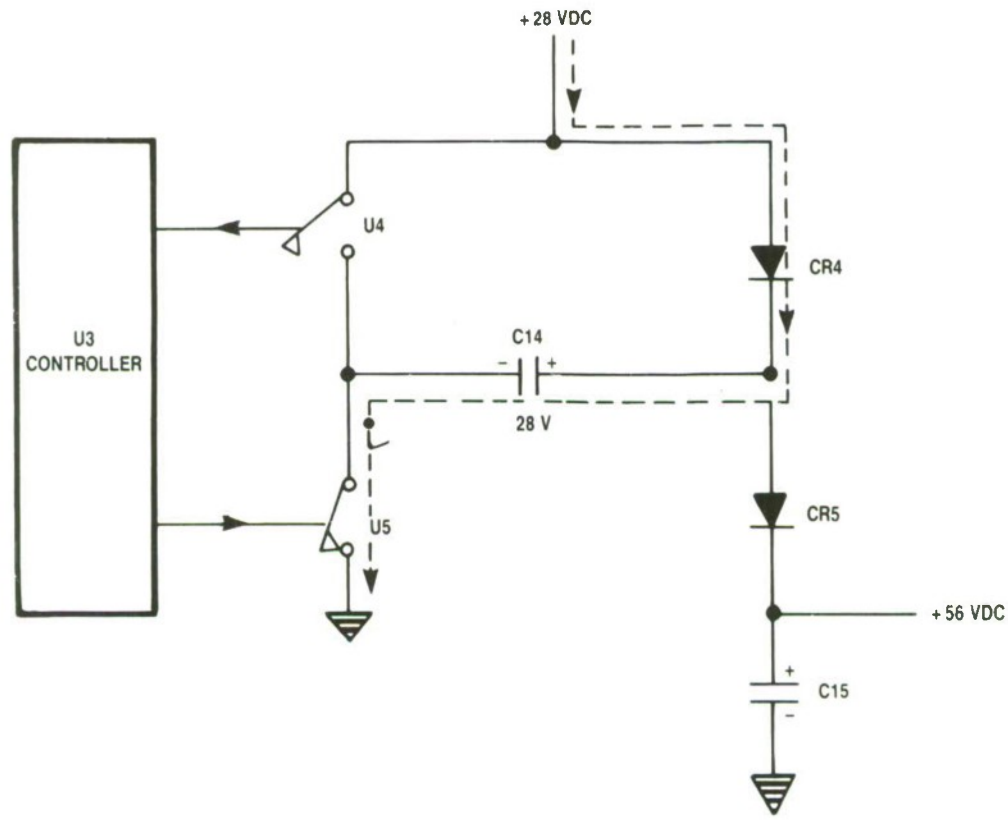

Figure 2. Active Voltage-Doubler, Cycle 1

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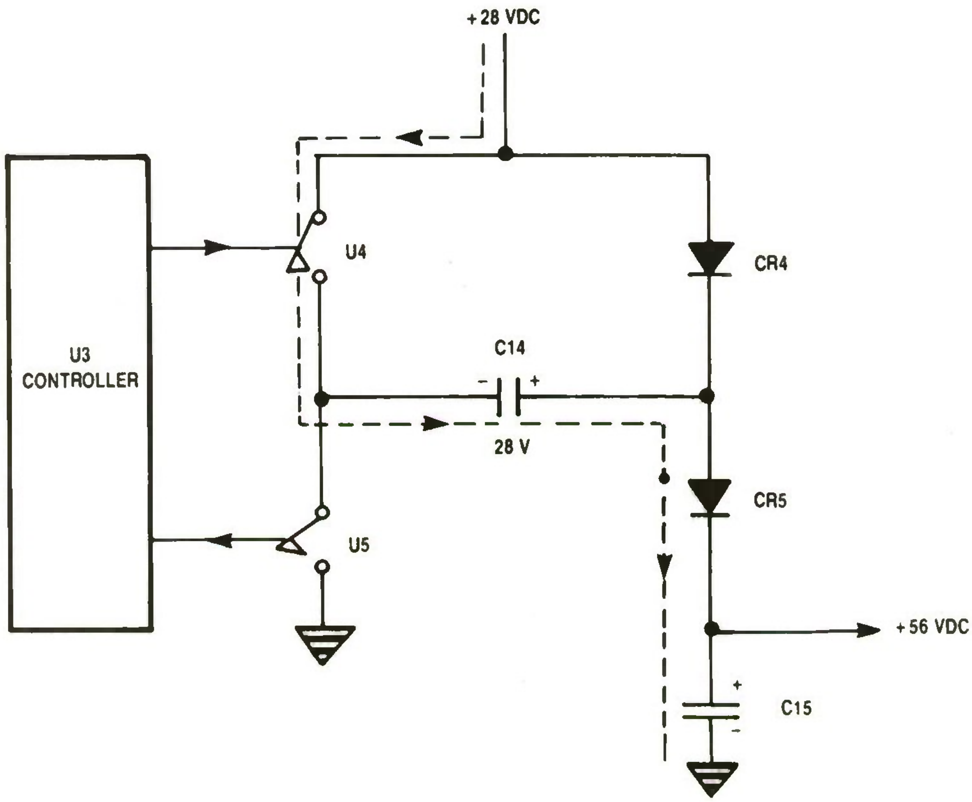

Figure 3. Active Voltage-Doubler, Cycle 2

When the voltage across C15 is less than this sum, a current will flow from the +28 V dc supply through U4, C14, and CR5 to charge C15 toward +56 V. No current flows through diode CR4 because it is reverse-biased by the voltage across C14.

Since both cycles are repeated approximately 65,000 times per second, capacitor C15 is quickly charged to 56 V dc. If the remote telephone loops are not being used, then no load current flows and C15 remains charged to 56 V dc. The switching continues, but no current flows through C14 to C15. When remote telephone loops are connected, a load current flows, which tends to discharge C15. This charge is replaced by current flowing during cycle 2. As heavier loads are applied, the output voltage of the active voltage doubler will decrease gracefully.

2.3 SHORT-CIRCUIT PROTECTION

Figure 4 is a simplified block diagram of one of the two short-circuit protection circuits. It consists of four major blocks: a series switch, an output current sensor, an output voltage sensor, and a free-running oscillator. The series switch is depicted as an on/off switch in series with a variable resistor. This abstraction is useful because it properly separates the two switch functions: output current control and output voltage control. The output current sensor block controls the current-limiting portion of the switch (shown as a resistor), while the output voltage sensor controls the output voltage portion (shown as an on/off switch).

2.3.1 Output Voltage Sensor

The output voltage sensor monitors the circuit voltage to a remote telephone loop. Should the output voltage fall below approximately 24 V, the sensor will react by opening the series switch and cutting power to the loop. This action limits the drain on the AN/TAC-1 power supply and the power dissipation of the series switch element.

2.3.2 Series Switch and Output Current Sensor

The series switch element dissipates power because of its series-resistive component. The magnitude of this component is determined by the output current sensor block. The output current sensor block continuously measures the load current. When the load current is below 100 milliamps, the magnitude of the switch resistance is small. As the load current approaches 250 milliamps, the

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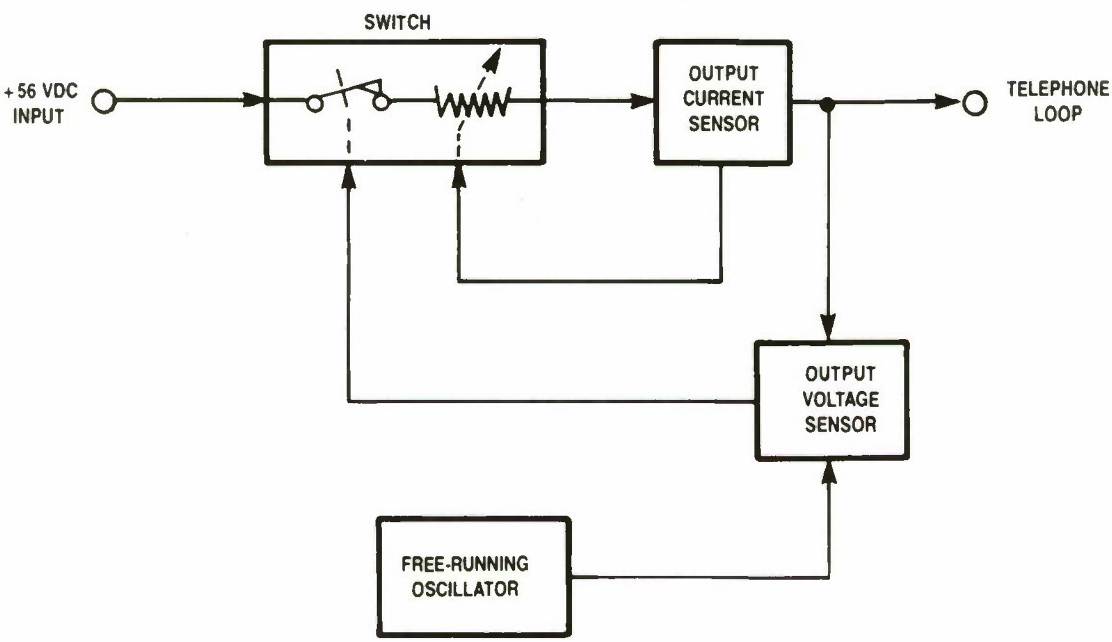

Figure 4. Short-Circuit Protection Circuit

sensor begins to rapidly increase the switch resistance to prevent the load current from becoming even greater. As the switch resistance increases, so does its power dissipation. Before the power dissipation becomes too great, however, the voltage drop across the switch resistance will cause the output voltage to fall below 24 V, and the output voltage sensor will open the series switch and force the output current to zero.

2.3.3 Free-Running Oscillator

Once the output voltage sensor opens the series switch and cuts power to the telephone loop, both sensor circuits lose their ability to function. The output voltage and current they are intended to control have both been reduced to zero. This condition would be permanent except for the free-running oscillator circuit. This circuit is designed to periodically force the output voltage sensor to momentarily close the series switch and restore power to the telephone loop. During this moment, if the overload problem has been previously corrected, the output voltage sensor circuit senses the rise in output voltage on the loop and keeps the series switch closed after the free-running oscillator times out.

If the overload problem has not been corrected when the oscillator times out, the output voltage sensor again opens the series switch to remove power from the telephone loop.

2.3.4 Status Lights

The combination of switch, output voltage sensor, output current sensor, and free-running oscillator provides overload protection for both external telephone loops, and automatic restoral of power when circuit faults have been corrected. Additionally, these two independent protection circuits operate status lights on the power supply control panel of the AN/TAC-1. These lights will be illuminated continuously when power is available to operate the remote telephone loops. Should one telephone loop become disabled because of an overload condition, the status light for that loop would extinguish to provide a visual indication of the fault. Additionally, the normally extinguished light will flash briefly once every 2 to 3 seconds to indicate the circuit is trying to automatically restore the power.

SECTION 3

THEORY OF OPERATION

The schematic diagram for the Telephone Battery Supply Subassembly of the AN/TAC-1 is shown in figure 5. It depicts all of the components on the printed wiring assembly. This theory of operation will follow the block diagram of figure 1, which divided the telephone battery supply into two parts: active voltage-doubler circuit and short-circuit protection circuit.

3.1 ACTIVE VOLTAGE-DOUBLER CIRCUIT

The active voltage-doubler circuit consists of active components U3, U4, and U5 along with additional supporting components. U4 and U5 are hybrid power circuits; each metal, 5-pin, T066 case contains an electrically isolated power transistor along with a smaller transistor connected as its driver. Both hybrid devices switch electrical current flow on or off. High-speed power diodes CR4 and CR5 also switch electrical current. The on/off cycle of diode CR4 is controlled by the on/off cycle of U5. Similarly, diode CR5 is controlled by U4. The purpose of the switching action of U4/CR5 and U5/CR4 is to charge capacitor C14 to 28 V dc and CR15 to 56 V dc. C14 and C15 are special aluminum electrolytic capacitors manufactured by Cornell-Dubilier and designed for high-frequency capability, long life, and high temperature operation.

U3 is Motorola Semiconductor's switching regulator control circuit. It produces alternating connections to circuit ground on its open-collector output pins, 11 and 13. A special feature is an internal "dead time" comparator that prevents both output pins from being connected to circuit ground simultaneously. When either output pin is disconnected from ground and floats to the open-circuit potential, the other output pin will not be immediately connected to ground. Rather, a period of time elapses when both outputs float before the other is switched to circuit ground. This allows the power hybrid switch, U4 or U5, to fully turn off before the other device turns on. If both devices were ever allowed to conduct simultaneously, the +28 V dc supply line would be shorted to circuit ground through their series connection.

The maximum dc supply voltage on pin 10 of U3 is 30 V. CR3, a 10 V zener diode, protects U3 if the +28 V dc supply line should exceed the maximum. The free-running frequency of U3 is established by R25 and C13. The applicable formula is $f_p = 0.55/RC$. R26 and R27

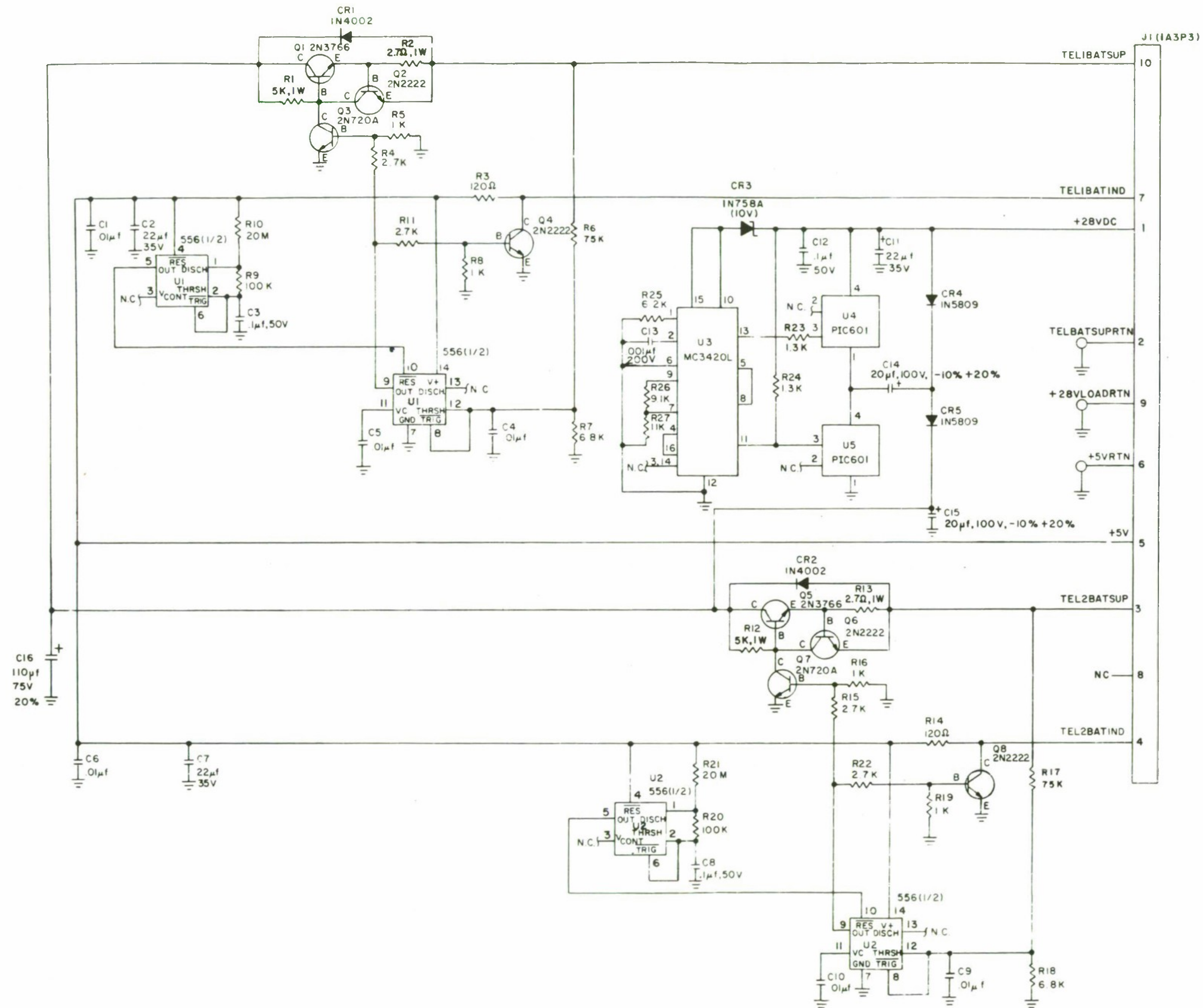

Figure 5. Telephone Battery Supply (1A3A1) Schematic

divide the reference voltage present at pin 9 of U3 and apply it to pin 7 to establish the amount of dead time. Resistor R23 limits the current flow into the pin 13 output of U3; R24 serves as a pull-up resistor on the pin 11 output.

U3 switches its two outputs, pin 13 and pin 11, to circuit ground at the free-running frequency established by R25 and C13. When pin 11 goes to ground, the transistor switch U5 is turned on and grounds the negative terminal of C14. This causes the diode CR4 to become forward biased, and the diode conducts and charges C14 to the polarity shown in the schematic. Subsequently, U3 will float its pin 11 output, and R24 will pull it high and turn off U5. After a bit of dead time, when both pins 11 and 13 of U3 are floating, pin 13 will be switched to ground. This will turn U4 on and connect the +28 V dc power line to the negative terminal of C14. This places the positive terminal of C14 at a positive potential of approximately 56 V dc, which forward biases CR5 turning it on and reverse biases CR4 turning it off. Current flows from the +28 V dc line through U4, C14, and CR5 to charge the positive terminal of C15 toward +56 V dc.

C15 will not be completely charged to +56 V dc in a single cycle, of course, because as C15 charges, C14 discharges. Instead, each cycle consisting of U4 being driven on and then U5 being driven on will charge C15 a fraction of the way toward +56 V dc. While this charging current is greater than the load current, C15 will charge to a potential that is approximately double the +28 V dc input potential.

3.2 SHORT-CIRCUIT PROTECTION CIRCUIT

There are two short-circuit protection circuits on the telephone battery supply printed circuit board. One protects the dc output TEL1BATSUP; the other protects the dc output TEL2BATSUP. Because they both operate identically, only the circuit protecting TEL2BATSUP will be discussed.

3.2.1 Output Current Control Switch

The output current control element is Q5, a 2N3766 NPN power transistor. This element acts as both a switch and a variable resistor between the active voltage-doubler power supply and the remote telephone load. The connections TEL2BATSUP and TELBATSUPRTN connect the transistor output to the telephone load.

Q7 switches Q5 on and off. Q7 is a small-signal NPN transistor capable of bypassing the drive current of Q5 and forcing it off.

Drive current for Q5 is provided by resistor R12, which connects the collector of Q5 to its base. This drive current is sufficient to maintain Q5 in a normally on condition. However, when the base of Q7 is driven to a potential greater than approximately +0.65 V dc, then the collector-to-emitter resistance of Q7 becomes very low and shorts the base drive current of Q5 to ground. With its base drive removed, Q5 turns off and disconnects the remote telephone from the active voltage-doubler power supply.

3.2.2 Indicator Light Control Switch

Q8 is an NPN small-signal transistor that performs a similar function to Q7. When Q7 is turned on, so is Q8. However, whereas Q7 shorts the base drive of Q5 turning it off, Q8 bypasses the drive current to the TEL2 indicator light turning it off. Resistor R14, one side of which is connected to the +5 V supply line, normally provides current drive to light the indicator. When Q7 turns on, the current is shorted to ground instead and the indicator light extinguishes. The indicator light status reflects the availability of power to the remote telephone. When the indicator is on, power is available. When it is off, power has been removed because of a fault condition.

3.2.3 Output Current Sensor

The output current sensor circuit consists of Q6 and R13. Q6 is an NPN small-signal transistor, which is used to bypass some of the base drive current of Q5. When Q6 begins to conduct, it will divert some of Q5's base drive current. This causes the series-resistance of Q5 to become greater which, in turn, reduces the amount of current flowing to the remote telephone load. Resistor R13 is used to sense the current flowing to the remote telephone load. The voltage developed across R13 is directly proportional to this current. As load current increases, so does the voltage drop across R13. This voltage is also impressed across the base-to-emitter junction of transistor Q6. When the voltage increases to approximately 0.65 V, transistor Q6 begins to conduct and bypasses some of Q5's base drive current. When some of Q5's base drive is removed, its resistance increases, which reduces the load current. The reduced load current, in turn, reduces the drop across R13, which reduces the conduction of Q6. This series of related causes and effects constitutes a closed-loop feedback system. This system operates to allow a continuous range of load currents from zero to some upper limit. This upper limit cannot be exceeded because the feedback will hold it approximately constant. The upper limit is set by the value of R13. Since Q6 begins to conduct and limit the output current when the voltage drop across R13

reaches 0.65 V, the current limit is 0.65 V divided by 2.7 ohms or 0.24 amps. The upper current limit is approximate because the conduction point of Q6 varies from transistor to transistor; 0.65 V is only an average value. Additionally, the current gain of the transistor used also varies and affects the upper current limit value. However, since a precise upper limit is not required in this application, the simplicity of the circuit has resulted in its selection and use.

3.2.4 Output Voltage Sensor

The output voltage sensor circuit limits the stress on the AN/TAC-1 power supply and the telephone battery supply circuitry. When the output current sensor causes the resistance of Q5 to increase to limit the output current, the output voltage begins to drop. As the output voltage drops, the voltage across the collector-to-emitter junction of Q5 increases proportionally. Since feedback is holding the current nearly constant at this time, the power dissipation of Q5 increases in direct proportion to the increase of its collector-to-emitter voltage. As the load resistance decreases, Q5 is forced to dissipate more and more power to hold the load current constant. Obviously, a halt needs to be called some time before Q5 burns up. It is the purpose of the output voltage sensor circuit to put a stop to this process before Q5 self-destructs.

The output voltage sensor measures the value of output voltage to determine when to stop any further increase in power dissipation. At approximately 20 V, it will turn on Q7 and short all of Q5's base drive to ground, turning it off. At this time, the output voltage will drop to zero. The sensor will measure the zero output and hold Q5 in the off state. Half of U2 performs the voltage sensor function. This half is connected to operate as a comparator with hysteresis. Normally, the output of the comparator, pin 9, is approximately zero, Q7 is held off by R16, and Q8 is held off by R19. The power switch Q5 is on, and the full supply voltage appears on connector pin J1-3 (TEL2BATSUP). The output voltage on J1-3 is attenuated by a resistive divider consisting of R17 and R18 connected to the input of the comparator at pin U2-8-12. When the comparator input falls below approximately 2 V, its output U2-9 will go to nearly 5 V and turn on Q7 and Q8 through R15 and R22, respectively. This will turn off power switch Q5, reducing the output voltage to zero, and will turn off the indicator light to show that power to this telephone loop has been removed.

3.2.5 Free-Running Oscillator

Normally, the telephone loop power would stay off until the fault was removed from the telephone loop, and the AN/TAC-1 was turned off and then on again. But it is desirable that the circuit automatically reset itself when the fault is removed. This is accomplished by using the second half of U2 to construct a free-running oscillator with a very low frequency of operation, approximately a cycle every 1 to 2 seconds. A cycle consists of a single, low-voltage pulse of very short duration, with the level about +5 V dc otherwise. This low-going pulse forces the output voltage sensor comparator off and momentarily closes the power switch to restore power to the faulty loop. If the problem on the loop remains, the output voltage on the loop will not rise. When the oscillator pulse ends, the output voltage sensor will again disconnect the loop. If the problem has been fixed, however, the voltage on the loop will rise. When the oscillator pulse ends, the output voltage sensor will measure a loop voltage greater than 20 V and will not disconnect the loop. This effectively restores power to the loop and automatically places it back in service.

This method of restoring power to a failed loop involves stressing the power switch components. For example, if the loop were shorted, the power switch would be forced on causing a short circuit. This stress level could be tolerated because the output current sensor would continue to operate independently and limit the output current to approximately 0.24 amps. Additionally, the frequency of this occurrence is very low and its duty cycle is quite short. These factors further operate to keep the stress on the circuit within reasonable limits.

The free-running oscillator consists of the second half of U2 along with the additional components R21, R20, and C8. The charge time, or time the output is high, is given by the formula hi-time = 0.693 (R21 + R20) C8. The discharge time, or time the output is low, is lo-time = 0.693 R20 C. The computed values are 1.39 seconds for hi-time and 0.007 seconds for lo-time. The total period is the sum of both hi- and lo-time or 1.397 seconds. Because of component tolerances, these times can be expected to vary somewhat from circuit to circuit. These variations, however, should not cause problems. The lo-time is important from the standpoint of power dissipation because during this time the power switch is forced on, even though the loop may be shorted. This time, then, should be kept relatively short so that the power switch does not overheat. Alternatively, this 0.007 seconds is a small percentage of the overall 1.397-second cycle; therefore, the average power dissipation is low.

SECTION 4

TESTING

The telephone battery supply will be tested by applying primary power to connector J1 and measuring voltages and waveforms at different points on the circuit board.

4.1 INPUT POWER

DC input power will be applied to the telephone battery supply circuit card assembly at connector J1. Specifications ±5% are as follows.

Name	J1 Pin	Specification
+28VDC	1	+28 V dc input power
+5VDC	5	+5 V dc input power
+5VRTN	6	+5 and 28 V return leads
+28VLOADRTN	9	Connect to J1 pin 6
TELBATSUPRTN	2	Connect to J1 pin 6

4.2 OUTPUT VOLTAGE

Subsequent to the application of input power, measure the output voltage with a dc voltmeter at J1 pin 10 (TEL1BATSUP) and pin 3 (TEL2BATSUP) with respect to pin 2 (TELBATSUPRTN). The measured value should be greater than twice the value of the +28 V dc input (measured between J1-1 and J1-6) less 2.0 V. Sequentially load each output with a 470 ohm load resistor capable of dissipating at least 6.67 watts. The output voltage at the loaded terminal should remain greater than 40.0 V.

4.3 SHORT-CIRCUIT PROTECTION

Connect the anode of an ordinary 25-milliamp indicator light emitting diode (LED) to pin 4 of J12, and the cathode to pin 6. The LED should be illuminated. Subsequently, short pin 3 of J1 to pin 6 for at least 30 seconds. Observe that the LED is normally extinguished but illuminates momentarily about once every 2 seconds. Then remove the short circuit and observe that the LED flashes on and remains in that state within 5 seconds of the removal of the short.

Subsequently, perform the same test with the anode and cathode of the LED connected between pins 7 and 6 of J1, respectively, while shorting pin 10 to pin 9.